Seismic Tracking for a Distributed Sensor Network with Collective Computation

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Abstract

A Distributed Sensor Network with Collective Computation (DSN-CC) is a group of sensor nodes, each with the ability to make measurements, communicate with other nodes in the network, and perform some data processing. The goal of the DSN-CC team is to develop a network using these nodes that can perform in-situ sensing and collective data processing that is both versatile and efficient. With motivation of developing the ability to track a vehicle using DSN-CC, we investigated the feasibility of determining direction to moving vehicles using seismic particle motions measured on 3-component receivers. We measured the particle motions using a 1440 x 1740 meter array of 3-component geophones located near Hobbs, NM. The geophones were in 12 rows spaced 120m apart. Each row had 58 geophone spaced 30m apart. We drove a small pickup truck along a road running N-S through the middle of the array. A handheld GPS receiver was carried in the truck to record the position of the truck as it traveled south on the road with a velocity of approximately 30m/h. The beginning of the seismic records was synchronized to begin with the handheld GPS receiver records. The 3 seismic records obtained range in time from 20 to 100 s. From the seismograms, we calculated possible azimuths, the angle clockwise from north, to the moving target, following the method by Flinn 1965, solved in the frequency domain. To solve for the trajectory of the truck we need at least two geophones, but due to uncertainties in the azimuths and the geophone locations we approached the problem statistically. We calculated the trajectory of the moving target to within 50m using the rows of geophones immediately to the west and east of the the road, which were recorded in the longest seismic record.

Introduction

What is DSN-CC?

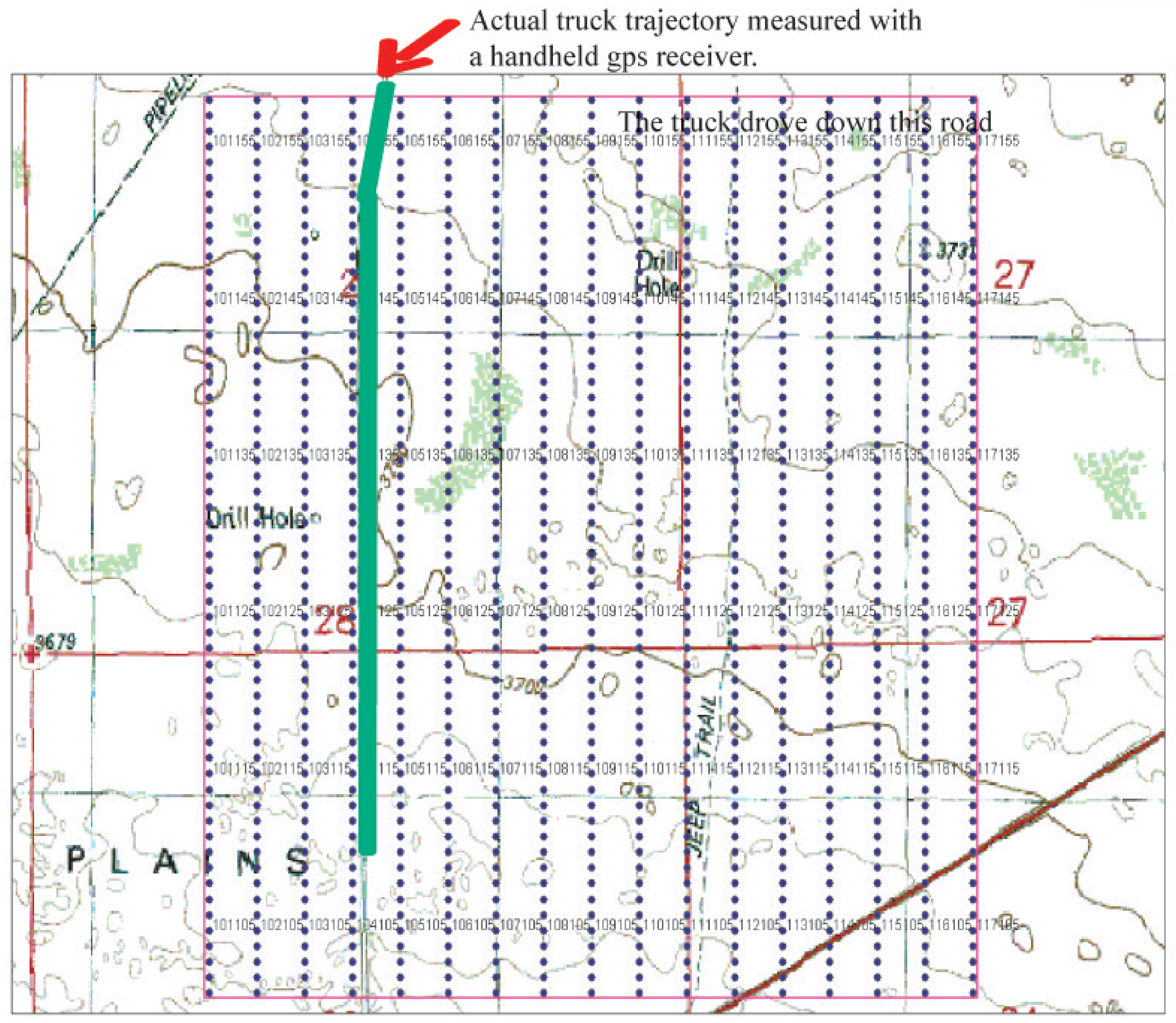
* A Distributed Sensor Network with Collective Computation (DSN-CC) is a group of individual nodes that work together to sense, perform calculations, and make conclusions as one unit.

* A DSN-CC differs from a classical network of sensors in the fact that it does not contain a central processing point, which makes the DSN-CC more energy efficient and less vulnerable to an attack on that central location that would render the network useless.

What is seismic tracking?

* Seismic detection would be one phenomenon that could be used for determining intrusion into an area being monitored by a DSN-CC. Seismic waves generated by a moving vehicle, for example, could be used to detect and track the vehicle. To minimize network communication requirements, we looked at the feasibilty of determining the source location by measuring direction to source independently at each sensor node. We determined directions to source using particle motions of surface waves recorded on 3-component geophone (velocity sensors). In principle, then, the location of the vehicle could be determined across the network by only sharing direction and time data.

Data



Data was obtained from the first 12 of these rows. The rows were 120m apart with 58 geophones, each 30m apart, in each row.

An example 3-component seismogram. The top one is the North-South component. The middle one is the East-West component and the bottom graph is the vertical component.

The seismograms from one row (number 104) showing the surface (Rayleigh) waves generated by passage of the truck.

Methods

* Used Principle Component Analysis to calculate the direction and linearity of the particle motions in the ground.

* Found the time and frequency ranges in which the particle motions were the most linear. Only ranges with an ellipticity greater than or equal to 0.9 were used.

* Calculated the possible azimuths (the angle clockwise from north) to the truck with respect to each geophone using these frequency ranges of high ellipticity.

* Used these azimuths and the positions of the geophones themselves to calculate the trajectory of the truck using our program called "movingtarget."

Movingtarget

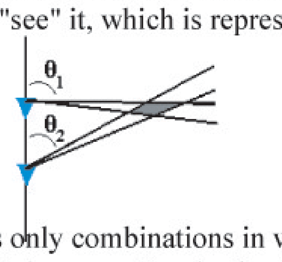
Uses a series of rejection criteria and mathematical calculations to form a trajectory of a moving target.

Rejection #1 : Movingtarget uses only geophones that had at least ten azimuth measurements, lowering the possibility of using random azimuths that were not part of a continuous signal.

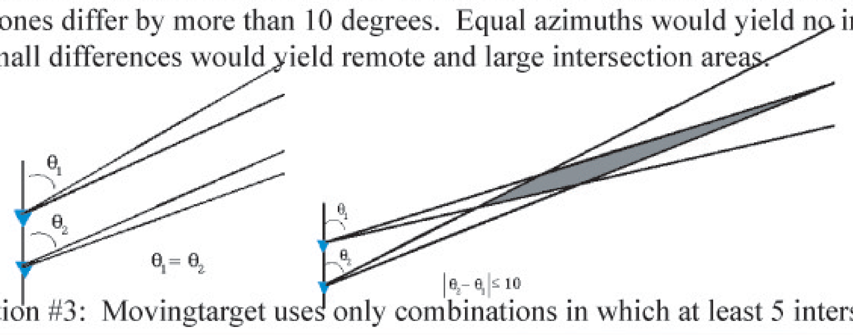
Then movingtarget uses the formula below to calculate all of the possible combinations of two geophones left after the first rejection.

$$\binom{m}{2} = \frac{m(m-1)}{2}$$

Movingtarget looks at pairs of geophones and the azimuth measurements from them at each time interval. For each time, it finds the intersection of the lines formed using the azimuths. Since there is some error in the azimuth measurements, these lines are represented by cones. The intersection of cones from two geophones gives the position of the truck for that time as they "see" it, which is represented by the shaded region.

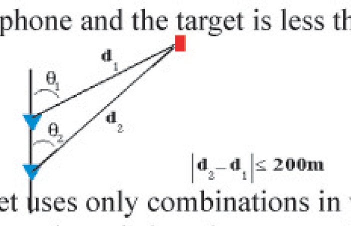


Rejection #2: Movingtarget uses only combinations in which the azimuths of the two geophones differ by more than 10 degrees. Equal azimuths would yield no intersections and small differences would yield remote and large intersection areas.

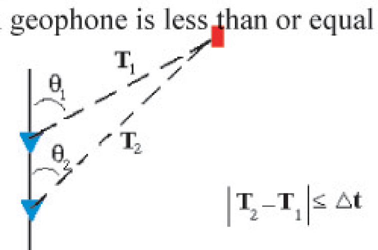


Rejection #3: Movingtarget uses only combinations in which at least 5 intersections exist.

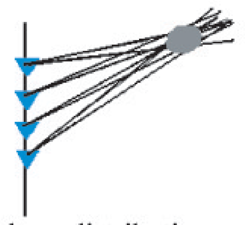
Rejection # 4: Movingtarget uses only combinations in which the difference in the distance between each geophone and the target is less than 200m.



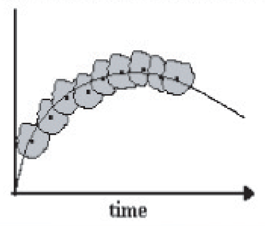
Rejection #5: Movingtarget uses only combinations in which the difference in the time for the wave to travel to each geophone is less than or equal to the sampling rate chosen.



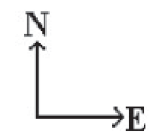
Movingtarget then finds a distribution of points from the remaining intersections per time.



Movingtarget plots each of these distributions per time chronologically, creating a possible path for the target. The average of these distributions gives the trajectory of the truck as "seen" by the geophones.



Results



The trajectory of the moving target calculated using seismic tracking. The blue triangles are the geophones. The left line is row 104 and the right line is 105. The green path is the actual trajectory of the truck. The black points are the positions of the truck calculated using the geophones and the red lines are the error bars in the East-West direction. The black points and red error bars on the left graph were calculated by finding the mean of the position distributions found by the azimuths. The black points and red error bars on the right graph were calculated using a weighted mean. The points were weighted according to the amount of error associated with them including errors from the azimuth and positions.

Acknowledgments

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Error Analysis

There were three main sources of error in our results:

Error in geophone positions

* The geophone positions were obtained with GPS. These positions were accurate to about 2 to 5 m.

Error in the azimuths

* The azimuths calculated using the seismic data were accurate to about 2 to 5 degrees. When calculating the intersection of the lines with these azimuths as slopes, a single point could not be pinpointed. Instead a distribution of points was found that gave an area of where the two geophones "thought" the truck was.

Errors caused by time delays

* Due to the time it took for the seismic wave to propagate through the ground, a time shift in where the signal from the truck appeared in the seismograms arose. This caused an error in the calculations the algorithm performed because it uses a single time throughout all of the seismograms.

* We reduced this error by finding the peak signal of each seismogram before entering the algorithm and using that as a marker in synchronizing the seismograms.

Future Work

More rows

* Preliminary results of trajectories calculated using more than just two rows of geophones have been obtained, but have not been analyzed. More work needs to be done to make the movingtarget program less specialized and computationally intensive.

More than one moving target

* Tests on the robustness of the algorithm created for this problem are needed to acertian whether it would be applicable in situations involving more than one moving target.